Initial Estimates of the Size/Structure/Competitiveness of Various Aspects of the National and International Robotics and Intelligent Machines Industry

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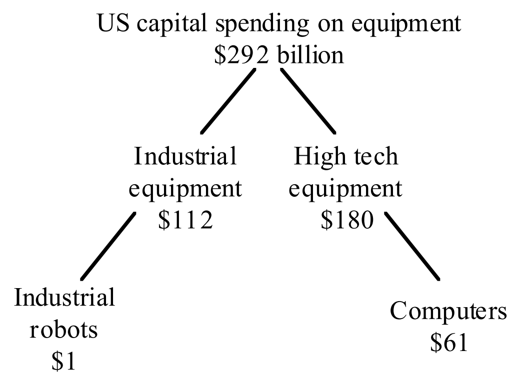
Introduction

A market for Robots and Intelligent Machines (RIM) exists wherever there is an interface between computers and the handling of physical objects. That broad definition opens up tremendous opportunities for growth beyond the arm-like industrial robots that are familiar today. While this paper is only a point of departure for identifying opportunities across the economy, large portions of the capital expenses of firms each year go to equipment that either is or could be part of this market. Exhibit 1 shows the magnitude of the capital expenditures on equipment within the United States alone.

Exhibit 1: US Capital Spending neared $300 billion in 1994



Capital expense data provided by Steven Roach, Morgan Stanley

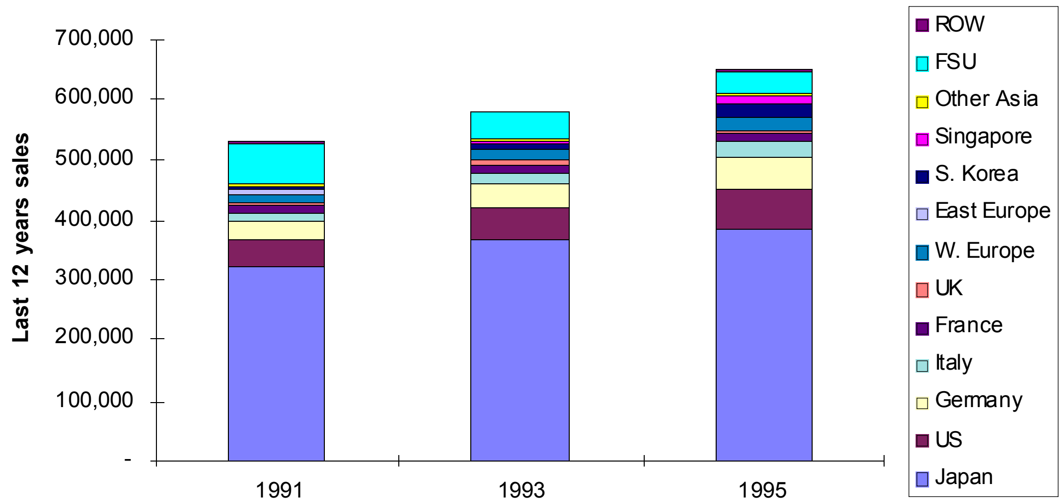
Despite this vast opportunity, the US RIM market, represented by industrial robots, was only $1 billion in 1996 - and the world market was only $5.7 billion in 1995[1]. While this is by no means a small market, the illustration above clearly shows that industrial robots are merely scratching the surface of a market that could encompass large portions of nearly $300 billion in annual expenses in the US, and multiples of that across the industrialized world.

Though RIM is a key technology for the twenty-first century, it is being overwhelmingly used to replace assembly line practices nearly a century old. Mass production created the automobile industry, but mass customization will revolutionize it and many other industries in the years to come. RIM is a perfect vehicle for leading this revolution and establishing the US at its forefront. This paper will describe the current robot market in the US and across the world, then discuss and size several potential service sector applications as a start to quantifying some of the potential benefits of a large, prosperous intelligent machine industry in the US.

Industrial Robots are a $5.7 billion market today

Industrial robots are in use in all the developed economies. Chart 1 depicts the share of robot installed base across the world. Japan is the most intensive user of robots, followed by the US, major European economies and South Korea

Chart 1: Industrial robot installed base is growing at 5.3% CAGR



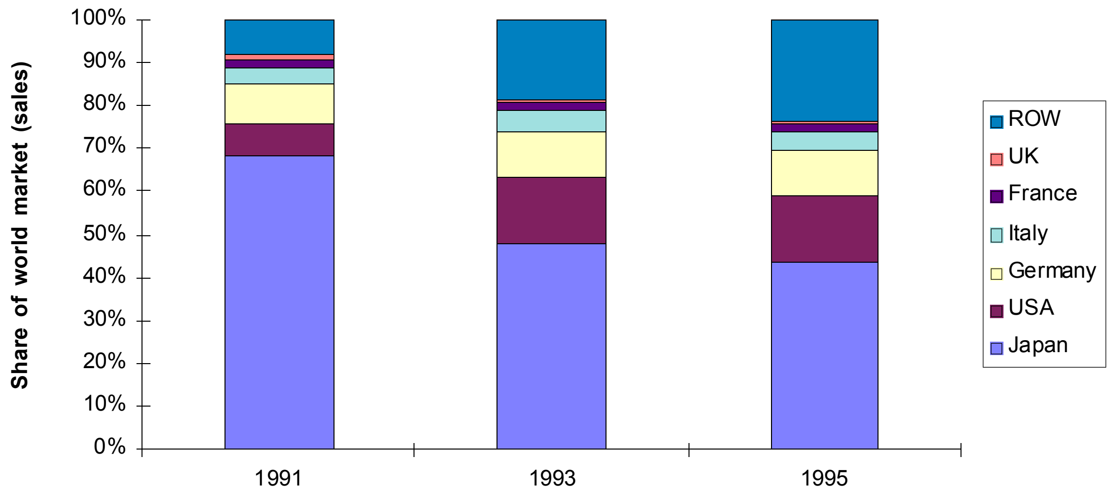
Source: United Nations/International Federation of Robotics, World Industrial Robots 1996, Geneva

While Japan continues to be the largest overall purchaser of industrial robots (largely from Japanese vendors), sales trends tell a slightly different story. Chart 2 displays the share of sales going into each country. As Korea increases its automotive industry and Singapore becomes a large electronics assembler, they became large purchasers of robots even as Japanese capital expenses were reduced during the Japanese recession.

Across the world, the automotive and electronics industries have been on the vanguard of implementing RIM. The prevalence of “dirty, dangerous and difficult” jobs in automotive and a high need for precision welding drove adoption in that industry, while miniaturization and fast product life cycles have been driving forces in using robots for assembly in electronics businesses. Across the world, RIM have been used in these two industries nearly exclusively, despite the presence of similar jobs in mining, agriculture, construction and meat packing - just to name a few. As a simple example, intelligent feedback and leveling technology could be incorporated into the operation of earth moving equipment. Surveys indicate that major US construction equipment dealers had 1994 revenues in excess of $3 billion.[2]

Not all RIM applications need to be large or sophisticated. Integrating feedback software and leveling devices into simple items like hand trucks or dollies could both create a large market in materials handling and substantially improve the ergonomics of many blue collar jobs today.

Chart 2: Other markets, particularly Asia, are growing in unit sales



Source: United Nations/International Federation of Robotics, World Industrial Robots 1996, Geneva

There is a great difference between countries not only in overall robot penetration, but also in the applications for which they are used. Table 1 lays out the different applications across countries. The dominance of the automotive industry as a user in the US accounts for the fact that more than half of American robots are used for welding. Adding the machining role which in many cases supports the automotive industry, nearly 80% of the US market may be accounted for by the auto industry and its suppliers. Even with the large installed base of robots in the automotive sector, however, there is still considerable room for growth.

Industry experts report that robot purchases from the sector are still at record levels as robots further permeate the industry in applications such as painting and precision seal application.

Table 1: Robot installed base shows opportunity in a wide range of applications

	Installed Base, 1995						
	France	Germany	Italy	Japan	UK	Korea	US*
Welding	32%	28%	25%	**20%**	39%	49%	**54%**
Dispensing	3%	5%	8%	2%	7%	2%	9%
Machining	12%	13%	29%	8%	11%		26%
Special processing	1%		11%		1%		
Assembly	11%	17%		**41%**	5%	26%	8%
Palletizing/ packaging	5%	4%		4%			
Material handling	18%	14%		2%	8%	3%	
Other	20%	18%	28%	23%	30%	20%	2%
Installed base	13,276	51,375	22,963	387,290	8,315	19,991	66,000

Source: United Nations/International Federation of Robotics, World Industrial Robots 1996, Geneva
* US data is based on 1995 sales – the US does not report stock by application area

While the US purchased 54% of its robots for welding in 1995, Japan has only 20% of its robots in such applications. The high proportion of robots in assembly represents use of robotics in the Japanese consumer electronics industry. The standardized nature of placing items on a printed circuit board and fast assembly rates of consumer electronics may suggest that some Japanese robots in these applications may not be as sophisticated as those needed in applications that require higher degrees of flexibility.[3]

Most robotics applications, even in Japan, have focused on substituting robots for people in repetitive tasks. While automation does add value, used in this way it realizes only part of the value of integrating computers and mechanical motion. The computing power exists today to use RIM in a truly flexible environment – not doing the exact same task over and over, but doing tasks that, while repetitive in general, are different for each particular item. RIM makes mass customization of manufactured goods a both a real and an economical possibility and could substantially increase the competitiveness of those firms and industries that lead in the flexible use of RIM technologies.

Table 3 indicates that the industry has consolidated over the past several years. Before the market contraction in the early 1990s, there were many participants and no clear leader. Now, major Japanese manufacturers like FANUC and Kawasaki compete with Swiss/Swedish ABB Flexible Automation for automotive orders, and Japanese Seiko and Sony compete with the US' Adept in light and electronic assembly.

This consolidation has come in part from large Japanese firms' selling products and expertise they developed as they built robot systems in house in the 1980s and 1990s. It has also been driven by acquisitions as foreign companies purchased marginal robotics businesses from US machine tool manufacturers like Cincinnati Milacron. Consumers largely

Table 3: Industrial robot manufacturing is rapidly consolidating

	Sales of top three firms $mil	World Sales	Share (%)
1991	659	6600	10%
1993	735	3700	20%
1995	1850	5700	32%

Source: United Nations/International Federation of Robotics, World Industrial Robots 1996, Geneva

purchase robot systems rather than individual machines, enhancing the scale benefits that accrue today to large companies that can maintain large groups of engineering and programming talent. Table 4 shows the largest players in the US market. Given that the US consumption pattern focused on welding and heavy assembly applications, it is somewhat surprising to see complete dominance of that market segment by international competitors.

Table 4: While foreign firms lead heavy assembly, US firms lead in lighter applications

Percent of US Market, 1995					
Heavy Assembly		Light Assembly		Electronic Assembly	
FANUC	30.9	**Adept**	**46.0**	Seiko	26.3

Percent of US Market, 1995					
Heavy Assembly		Light Assembly		Electronic Assembly	
Nachi	30.9	Seiko	22.3	**Adept**	**21.7**
ABB	22.6	Sony	7.0	Robodyne	20.6
Kawasaki	15.6	IaI	5.6	**Megamation**	**16.5**
		Yamaha	5.6	Sony	8.2
		Sankyo	5.2	Others	6.7
		Other	8.3		

Source: Frost and Sullivan in United Nations/International Federation of Robotics, World Industrial Robots 1996, Geneva
US firms are indicated in **bold**

Several growth opportunities remain within manufacturing

A key measure for assessing the potential for further industrial robot penetration in the US and other major economies is what the UN calls “robot density.” Robot density is calculated as the number of robots per 10,000 workers. Table 5 shows the vast difference between Japan and the other major economies. Clearly Japan has been a far larger adopter of robotics than any of the other major economies. Moves by the US or other large economies toward Japanese use levels could dramatically increase the size of the market. Even a US market move toward Germany’s level of robot use would suggest a 62% increase in robot use that would push the US robot market toward $2 billion – and this growth is *before* any new applications in the service sector are considered.

In addition to the potential increases in market size in lower penetration markets like the US, the data suggests that the market growth may also come from substitution. Particularly in Japan, the large difference between the total robot population and the population of advanced robots may indicate that an early generation of robots in Japanese assembly applications may be replaced over time with more sophisticated units.

Table 5: Robot density shows substantial degree of Japanese RIM implementation

	Robots per 10,000 manufacturing workers	
	All robots	Advanced robots*
Japan	251.5	209.5
US	35.7	32.1
UK	17.4	13.9
Germany	57.7	52.0
France	32.4	30.9
South Korea	64.3	51.4
Sweden	59.5	53.6

Source: United Nations/International Federation of Robotics, World Industrial Robots 1996, Geneva
* "Advanced" robots are trajectory operated and adaptive only

The difference in the labor market characteristics between national markets also suggests large opportunities for growth. Japan's high penetration can be thought of as a result both of its highly automated consumer electronics industry and the high cost and inflexibility of its labor market. However, South Korea has the next highest robot density – but it is coupled with a materially lower labor cost than Japan.

RIM implementation in lower wage cost/higher labor market flexibility countries suggests that advanced technologies provide more than a replacement for high cost labor. Robots deliver a high and consistent level of quality, and some low labor cost markets are not always capable of providing world class quality levels for their low price. Industry experts indicate that Western auto manufacturers are installing production lines in their Chinese facilities that use RIM technology – not because it is less expensive than labor but because it is the only way to guarantee the level of quality they expect.

RIM will also replace fixed automation developed in the 1980s and early 1990s with flexible automation. The Automation Forum of the Material Handling Industry Association did a survey in 1991 of the money spent on a variety of advanced manufacturing technologies. Nearly $40 billion was spent then on technologies ranging from C/NC machines to CAD/CAM systems to industrial robots. Even if the market has grown only 3% a year, that represents $46 billion opportunity today. While earlier investment was predominantly in fixed automation, much of that could become flexible automation using RIM.

Cost and functionality influences market growth potential

Increasing adoption of RIM technologies into new markets and applications depends on two simple factors - capability and cost. Over the last decade, cost per robot has come down substantially even as functionality of the devices themselves has significantly improved. According to the United Nations study, prices for robots themselves have dropped 21% between 1990 and 1995. This took place simultaneously with increases in world labor prices. As the gulf between dropping robot prices and rising wages increases, RIM will become increasingly valuable across a host of industries.

While increased functionality improves the value proposition for automation, the total market for industrial robot *systems* is likely three times as large as unit sales indicate. Robots themselves and their primary controllers are only 1/3 of a total installation cost. Specialized engineering and programming is necessary to transform a robot into a usable piece of automation.[4] Even if the US increased penetration of industrial robots rose to German levels, this would suggest a systems market of nearly $6 billion.

The high level of sophistication required to install an intelligent system has two effects that limit the current breadth of applications for robotic technology. First, specialized applications engineers are expensive to use, driving up the systems cost. Second, the high degree of customization needed to implement a system substantially increases the time investment necessary. Both factors together make implementing RIM a time and money intensive process. These barriers will only come down as systems become more standardized and easier to install and update. Software will be the driving force for this simplification.

Software and systems integration will increase in importance

Customers are demanding robot manufacturers provide them with more standardized control packages, improved graphical programming tools and PC based interfaces. As their demands are met, new users will be less tied to manufacturers to create complete systems. And as programming becomes more standardized, manufacturers will gain less advantage from scale in systems development. Standardization will enable small software developers and systems integrators to provide system solutions for a specific application in a particular vertical market (assembling cookies in the food industry, for example) and transform the manufacturer from a system provider into a component supplier. The shift in market power from manufacturers to service providers may, in fact already be in process. Large purchasers like automotive manufacturers purchase painting robots in full system bundles, but purchase welding robots independently and use systems integrators of their own selection to put the robots to use.

The US leads the world in the penetration both of computing in general and advanced computing systems. Table 6 shows the depth of computer power penetration across several major economies and the level of advanced computing (represented by MIPS) relative to the

Table 6: The United States leads the world in computer penetration

	Computers per 1000 people	MIPS per capita index
France	171.7	42.3
Germany	174.6	43.1
Japan	145.6	35.9
Korea	77.9	19.2
Sweden	244.1	60.2
UK	216.5	53.4
US	**364.7**	100.0

Source: Computer Industry Almanac, 1996

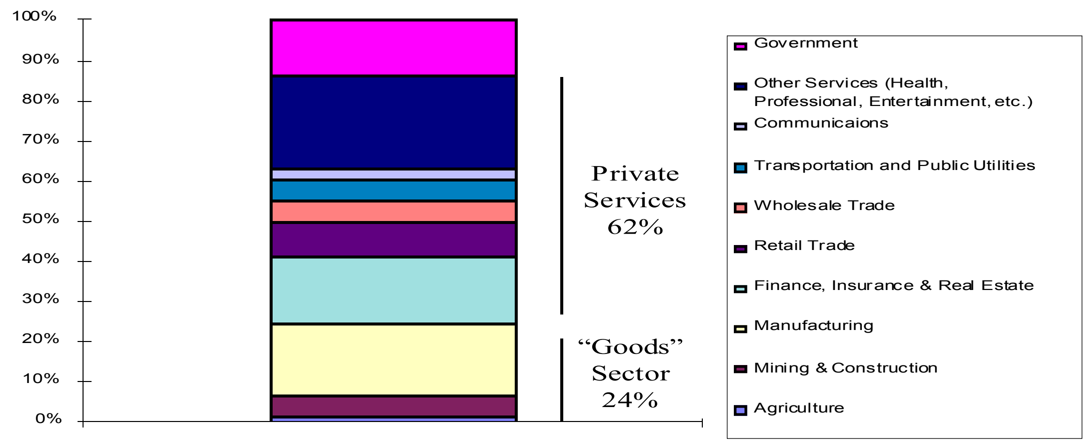
US index of 100. Combined with US dominance in software development, these trends suggest that the US has the raw capabilities necessary to succeed in the RIM systems marketplace. The leadership of the US in developing open architecture systems, with their multitude of specialized software developers, is one reason that computing has become so pervasive. Open architecture drives down costs in the PC industry today and could do the same in the intelligent machines industry of tomorrow.

Basic system economics suggests that the industries that support RIM assembly, such as software, may be in a better long term position in the value chain than hardware manufacturers. While a robot is a one time purchase, providing advanced capabilities through better controllers and software can become an annuity. Manufacturers serve both roles today, reconditioning robots after about seven years of service by upgrading their controllers and software. The existence of third party resellers of used robots like the Robot Shop suggests that manufacturers no longer have a lifetime relationship with their customers. Unbundling provides both a low cost entry for new users and assists in balancing the relationship between manufacturers and customers. The combination of simpler programming and less expensive systems using used equipment should shift market power from hardware manufacturers to vertical market specialists over time.

Macroeconomic shifts demonstrate growth of the service sector

While extensions of RIM technology into other manufacturing environments hold the potential to materially increase the use of intelligent machines, manufacturing is only a small part of the overall economy. Examining opportunities to use robots themselves or RIM

Chart 3: US GNP, 1995

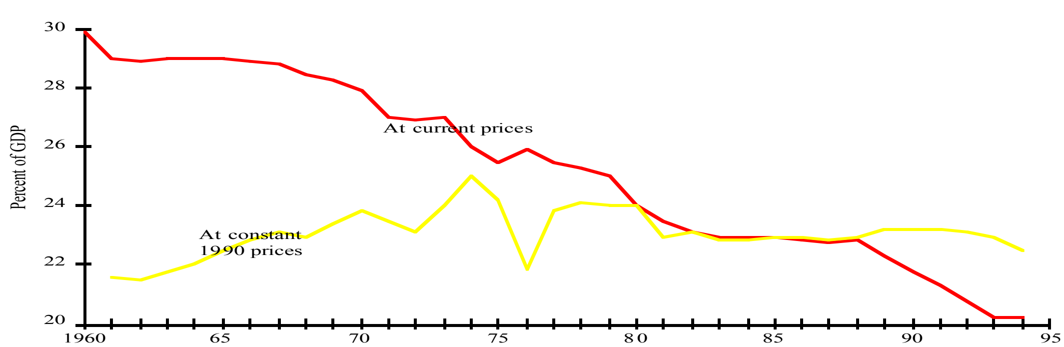


Source: US Bureau of the Census, 1996

technologies like machine vision and force feedback in the service sector opens up a much broader market. In the United States, manufacturing represents only 17% of the total economy, and the entire goods producing sector only 24%.

This trend is not limited to the United States. Chart 4 indicates that the share of GNP accounted for by manufacturing is less than 25% in most major economies.

Chart 4: Manufacturing share of GDP has accounted for less than 25% of developed economies since 1960

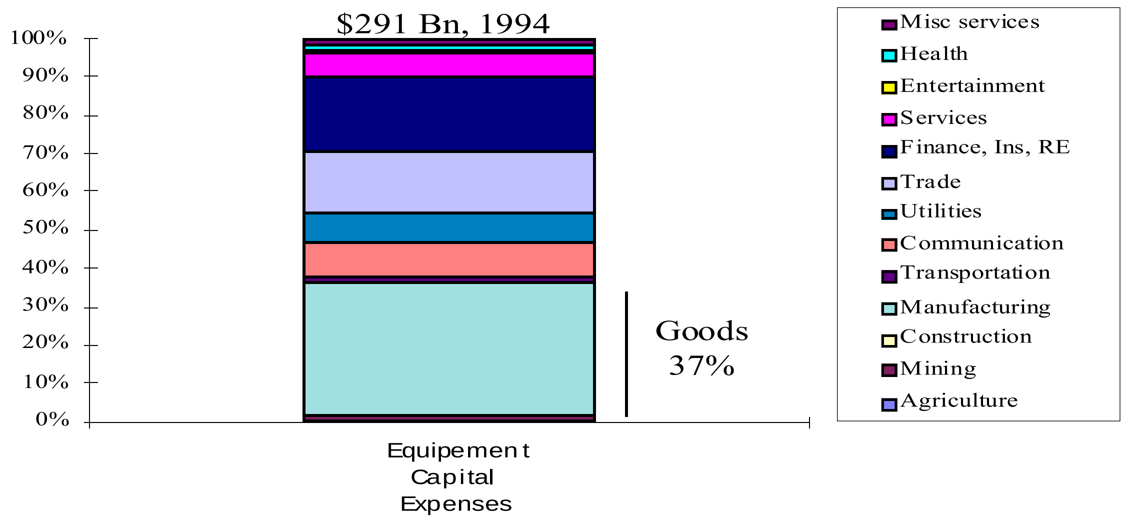


Source: IMF World Economic Outlook

Capital spending assists in scaling potential opportunities for RIM

While GNP figures help to identify the overall scale of the split between manufacturing and services, examining capital spending provides a better benchmark of those business expenses that either are for intelligent machines or could be spent on them in the future.

Chart 5: Capital Expenditures on Equipment, 1994



Source: Steven Roach, Morgan Stanley

Private enterprises spent $627 billion in 1994 on capital expenses across the US economy. Of that, Morgan Stanley reports that $291 billion was spent on equipment - machinery, computers and other goods that create the products and services used in the economy

Table 7 shows how Morgan Stanley's analysis allows the equipment expenses to be disaggregated into equipment types. Dividing the investment between basic industrial equipment and information technology makes the massive investment in computers dramatically clear. Not only is high tech investment higher than basic industrial investment, but more is spent on computers than on general and special industrial machinery combined!

Table 7: US equipment spending by type, 1994

Basic Industrial Equipment			High Tech Equipment		
	million $	% of total		million $	% of total
Special Industry Machinery	28,293	8%	Communication Equipment	81,470	45%
General Industry machinery	25,880	23%	Computers	61,375	34%
Metalworking Machinery	24,643	16%	Scientific and Engineering Instruments	23,358	13%
Electrical equipment	17,371	22%	Photocopiers	13,394	7%
Fabricated Metal Products	9,298	25%			
Engines and turbines	6,106	23%			
Total	111,591			179,597	

Source: Steven Roach, Morgan Stanley

The $1 billion invested in industrial robots falls largely under the category of "special industry machinery," 3% of total spending in that segment. At a very basic level, it is interesting to consider the US' leadership position in many industries on the right side of this table relative to industries on the left. RIM represents an opportunity to leverage technological leadership to reclaim advantage in industries on the left through the integration of computer technology with mechanics.

Service sector applications represent large RIM opportunities

There is still significant room for growth in the US market for industrial robots. As the preceding section demonstrated, however, the service sector comprises far more of the US economy and is growing in importance throughout the developed world. Focusing RIM efforts opens a much larger market space described in Table 8. This section will discuss initiatives in several service businesses to use RIM, and lay out conservative estimates for a few potential markets.

Table 8: Opportunity space for RIM across the US economy

Industry Group	Potential RIM Applications	1994 Equipment Spending ($ mil)
Goods Producing Industries		
Manufacturing	Advanced industrial robots	159,956
Agriculture	Automated harvesting, meat processing	24,027
Mining	Intelligent earth moving equipment	20,593
Construction	Intelligent earth moving and materials handling equipment	8,491
Services		
Financial Services	Electronic commerce, transaction processing	162,663
Trade	Intelligent inventory management systems	114,554
Utilities	Telerobotics in nuclear materials handling	58,277
Communication		40,410
Transportation	Intelligent materials handling equipment	25,982
Entertainment	Virtual reality gaming	6,481
Health Care	Less invasive surgery, hospital automation	3,524

Equipment spending source: Steven Roach, Morgan Stanley

RIM suggests several opportunities in trade

Manufacturing has used robots for packaging and palletizing for several years. While their investments in increasing efficiency have followed their customers' insistence on just in time inventory, moving finished consumer goods represents a substantial opportunity. Grocery sales exceeded $400 billion in 1995, general merchandisers like Wal-Mart and K-Mart sold $297 billion, and apparel retailers sold another $110 billion.[5] These and other leading retailers are beginning integrate their massive amount of point of sale data directly with automated warehousing. Automation initiatives increase accountability of goods, allowing retailers to more comfortably decrease their inventory levels. In apparel, for example, Saks Fifth Avenue has begun a $30 million warehouse in Aberdeen, MD that will use bar coding technology and conveyors to move its goods through its warehouse into stores faster. Executives at Saks expect to save $3-4 million in expenses per year from this one facility. Adding intelligence to warehousing can also increase throughput. Staples has spent $43 million on one advanced facility in Bowie, MD that has increased the productivity of its facility from 100 cartons per hour to 450.[6]

According to Morgan Stanley, retail and wholesale trade already spend $559 million on special industry equipment and $12.5 billion on computers. Assuming even one percent of this investment goes toward RIM represents more than a $130 million market in the near term, and substantially more as the benefits become clear throughout the industry.

Outside the commercial sector, the US military moves nearly 17 million line items through its depot systems annually. At a cost of approximately $25 per line item, the largely manual process costs taxpayers nearly $425 million per year. Automation within the Defense Logistics Agency could potentially bring benefits to the military similar to those seen by grocers and retailers.[7]

RIM allows rapid sortation of millions of packages daily

Package delivery companies like UPS and Federal Express created an industry by using information technology to get millions of packages to thousands of destinations for time definite delivery. Although commercial package companies compete for a fast growing market, the US Postal Service still carries nearly 70% of all two day packages.[8]

While UPS and Federal Express have already developed sophisticated tools for sorting, the USPS is beginning to use RIM to more effectively move flat and packed mail through its system. Its 1997 budget includes $67 million for developing an intelligent system to handle trays of flat mail. The software system designed for postal distribution centers systems is in its second phase and accounts for $38.2 million, while 100 robots are currently being fielded as part of a test program to improve tray loading, unloading and sorting. Its budget for this initiative is $28.9 million this year. If successful, the Postal Service could become a large user of RIM in the near future.[9]

Several potential uses for RIM exist in health and allied services

While complete automation of a hospital is far on the horizon, the health and allied services market offers several promising applications for RIM. The health care market is particularly attractive because consumers (health care professionals) already use a large amount of technologically sophisticated equipment and thus are likely to have a high comfort level dealing with another new technology. The United States, with its leading research hospitals and market leading medical device manufacturers, could stand at the forefront in this developing application for RIM.

The potential market is large. Spending on for-profit health services was $357 billion dollars in 1994, and non-taxable hospital spending accounted for another $301 billion.[10] A more narrow focus on capital spending shows electromedical equipment (excluding X-ray equipment) expenses exceeded $7 billion in 1995 according to the Electronics Industry Association. Table 9 breaks that into its component parts. Realistically, RIM could play a part in each of the four broad areas.

Table 9: Electromedical device market was $7.2 billion in 1994

	US Factory sales $ million
Diagnostic Equipment	2,300
Therapeutic Equipment	2,226
Patient Monitoring	1,380
Surgical Support and other	1,287
Total	7,193

Source: Electronics Industry Association, EIA Factbook, 1996

RIM can be used to perform microsurgery, enabling surgeons to use less invasive procedures. Initiatives are currently underway in coronary artery bypass surgery - three percent of the 301,000 procedures are done using advanced, minimally invasive practices. As this technology expands, it holds promise to capture a significant share of the $30 billion spent annually on open heart surgery.[11]

Other experiments combine current scanning technology with force feedback to increase a surgeon's precision in knee surgery. Before cutting, the surgeon marks a "do not cut beyond" line on a scan. A computer interprets the location chosen by the doctor. The doctor then uses a scalpel linked to a force feedback device that both limits any shaking in his motion and increases resistance on the scalpel as the selected point in space approaches.[12]

RIM assisted surgery is the glamorous face of technology in health care. On a more mundane level, Mercy Hospital in Pittsburgh has been using robots for several years in its pharmacy and now fills 85% of its prescriptions via the device. The machine dispenses drugs and can also automatically check for patient allergies and drug interactions with the hospital's computer. Pharmacists can then be freed from the mundane parts of their task and focus more on patient care.[13]

Outside the hospital, much of the routine work of laboratory research is proving to be fertile ground for RIM. Zencea, a UK drug company, screened 222,000 drug compounds in 1992. After developing robot cells to perform the task, throughput was increased to 345,000 compounds per MONTH. In the US, SmithKline Beecham reports a 10-50 fold improvement in its laboratory testing.[14] In a laboratory, RIM technology can be used to precisely measure and combine different materials thousands of times, then can also move them from one piece of equipment to another. Outside drugs, environmental testing has also benefited from RIM. A British water quality testing firm was able to save 2M pounds per year when they automated 85% of their three million tests while simultaneously improving speed and reliability. Consolidation in the US clinical laboratory will accelerate the pace of automation efforts. Clinical labs represented a $36 billion market in 1996.[15]

As life expectancies increase throughout the industrialized world, RIM technologies may be called on to better leverage health care workers. Experiments are underway to use robots to assist less mobile people in getting into and out of bed and with other simple care tasks. Simple yet intelligent automation could even be incorporated into individual prescriptions, dispensing the appropriate dosage to a patient at the appropriate time – a significant benefit for a population that may have limited memory.

Other benefits from RIM

A national RIM initiative could provide resources to assist a $1 billion industry to grow to multiples of its size by broadening its focus. Additional benefits will accrue in the form of better products and services for consumers, better jobs for workers, and the development of high technology supporting industries.

Robots in repetitive motion applications could cut part of a $12 billion health bill

Liberty Mutual Insurance is the largest provider of workman's compensation insurance. In 1994, it performed a large study of repetitive motion injuries and discovered that such injuries cost the US economy $563 million in 1989.[16] Many of the applications that result in such injuries could effectively be automated.

Table 10: 1989 Repetitive motion injuries by industry

	% of injuries
Instrument manufacturing	5.9
Clerical work	4.3
Office machine installation and repair	3.5
Clothing manufacturing	2.9
Meat packing	2.6

Source: Liberty Mutual Insurance

While data was not available by industry, the cost of lower back injuries is an significantly higher. Lower back injuries resulted in $11.3 billion in worker's compensation expenses in 1989.

RIM related employment gains will extend beyond robot assembly

Even if the US RIM market were to dramatically expand, the structure of the current industrial robot market does not suggest that it will be a large job provider. Robot manufacturing is largely an assembly process. FANUC, a leading Japanese robot manufacturer with revenues in excess of $1 billion, does so with fewer than 2,500 employees.[17] Adept leads in US light applications with a staff of less than 400. Growth in the hardware market will necessitate more applications engineers (a current bottleneck), but as implementing RIM within a factory or service facility becomes easier, fewer people will be needed to develop a given application. GM, for example, is able to reprogram an entire facility's robots (around 500) with a small cadre of GM engineers and fewer than fifty engineers and technicians to make changes necessitated by a product change.

While employment gains in robot assembly may not be dramatic, there is likely a multiplier effect associated with the software, specialized applications and supporting technologies that may result in additional employment gains as the overall RIM industry grows. Further research is necessary to quantify this effect.

Summary

The world industrial robot market has provided many technologies and tools that can generate cost savings and improve the quality of workers' lives. But industrial robots are only one face of a much larger market for intelligent machines – machines that link mechanical devices with computing technology. Even with increases only in industrial robots, the $1 billion US market could quickly double in size to $2 billion. As applications in the service sector are developed, these technologies capture material pieces of the nearly $300 billion spent annually on equipment in America. US leadership in many aspects of the service economy suggests that the US has the potential to take a leading world role in developing RIM uses there.

[1] World Industrial Robots 1996, United Nations/International Federation of Robotics,
[2] "Construction Equipment Trends," Merrill Lynch and Co. industry report, 16 May, 1995
[3] Duncheon, Charles, "The State of Assembly Robots in North America," in World Industrial Robots 1996, United Nations/International Federation of Robotics, p.221
[4] Duncheon, Charles, op cit
[5] Statistical Abstract of the United States, 1996, US Bureau of the Census
[6] "Swiftly coming to a store near you," Washington Post, February 24, 1997
[7] Telephone interview with Chris Krishnan, Defense Logistics Agency , 24 June 1997
[8] Market Share Reporter, 1997
[9] "Comprehensive Statement on Postal Operations," US Postal Service, 1996
[10] Statistical Abstract of the United States, 1996, US Bureau of the Census
[11] Wall Street Journal, June 19, 1997, p. B1
[12] "Robodoc," Economist, June 15, 1996
[13] "Pharmacy robot fills prescriptions flawlessly," Los Angeles Times, January 24, 1996
[14] "Robots invade the laboratory," Financial Times, November 9, 1995, p. 22
[15] "The Clinical Laboratory Industry," Smith Barney research report, December 20, 1995

[16] Brogumys, George, et al, “Recent trends in work related cumulative trauma disorders of the upper extremities in the US,” JOEM, April 1996, p 404
[17] Directory of Corporate Affiliations, National Register Publishing, 1996, p. 481

Appendix

Research Conducted

Primary Sources

Twenty interviews were conducted with participants in the RIM industry and trade associations that use or might use the technologies discussed here. Their input directed much of the secondary research, and their specific contributions are noted in the text.

Name	Organization
Glen Jennison	Ford Motor Company
John Rueping	Kodak
Klaus Nielson	UPS
Steve Holland	General Motors
Chris Krishnan	Defense Logistics Agency
Graham Mitchell	Industrial Research Institute
Jim Albus	NIST
Chuck Taylor	American Association of Railroads
Don Vincent	Robotics Industry Association
JB (John) Nofsinger	Materials Handling Institute
Tom Donahue	American Trucking Association
Brian Carlysle	Adept Technology
Guy Potok	ex FANUC
Silas Nichols	ABB Robotics
Ron Birch	Laitiam Corp
Steve Charles	Charles Institute
Steven Roach	Morgan Stanley
Tom Leaman	Liberty Mutual Ins.
Bob Brown	Deneb Systems
John Craig	Silman

Secondary sources

Much of the detailed information about current and exisiting markets was developed through extensive research in print and using computer databases like Lexis Nexis and Dow Jones. Government sources also provided much of the macroeconomic information. Additionally, Steven Roach at Morgan Stanley provided Morgan Stanley internal data that allowed the me to analyze the equipment component of enterprise capital expense

Suggestions for further research

The survey nature of this paper is such that further research can be done on virtually all the topics discussed here. Likely one of the most interesting and valuable topics to pursue would be a micoreconomic analysis of the productivity and health care gains actually resulting from RIM implementation. Macroeconomic approaches such as the mine or that used by the United Nations in their analysis of the automotive industry allow too much “noise” into productivity calculations that render them of little value.

Another valuable topic would be the limits of use of RIM technologies in some of the areas discussed. It is possible that the “robot hype” in the 1980s and its failure to deliver immediate value scared away many potential users. Understanding their rationale for not adopting RIM would help develop appropriate policy programs for encouraging American RIM industry growth.